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Do repeated wildfires promote restoration of oak woodlands in mixed-conifer landscapes?

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ABSTRACT

Oak woodlands are dependent on frequent fire to maintain the low stem density and diverse understories that typify these ecosystems. Without this recurrent disturbance, fire-sensitive conifer competitors encroach on oaks, reducing their vigor, and diminishing habitat quality. In fire-excluded oak woodlands, stand-replacing wildfire can trigger shifts in canopy dominance from seed-generated conifers to oaks, which are capable of vigorous sprouting following topkill. We examined the occurrence and sprouting dynamics of California black oak (*Quercus kelloggii* Newb.) following repeated wildfires in the Lassen National Forest, California. We found that following reburn, changes in oak relative stand dominance, as well as oak sprout basal area and height, were each positively related to fire severity ($P < 0.0001$ for each analysis). While conifer regeneration suffered complete mortality at moderate and high reburn severities, 97% of topkilled oaks resprouted from surviving rootstocks, reinforcing oak dominance. Black oak resprouts that originated following topkill in the first wildfire were frequently topkilled in the second fire, including at lower burn severities survived by advance conifer regeneration. The results of this study indicate that while as individuals, black oaks are resilient to recurring wildfire, restoration of historic woodland structure and function is an unlikely outcome of these repeated disturbances. Management of post-wildfire regenerating oak stands in this region will require supplemental fuel reduction treatments, including prescribed burning.

1. Introduction

Fire-dependent ecosystems, woodlands and savannas have existed for millennia in concert with natural and anthropogenic fire (Staver et al., 2011, Swanson et al., 2011). Frequent, low-severity fires maintain the open canopy structure and diverse herbaceous understories characteristic of these ecosystems. Low-intensity fires, propagated in herbaceous fuels, eliminate the ingrowth of fire-intolerant species, and sustain open canopies of fire-tolerant savanna trees (Engber et al., 2011, Engber and Varner, 2012, Veldman et al., 2013). These frequent fires create a negative feedback, preventing the accumulation of heavy fuels, and maintain an open canopy that allows for development of the herbaceous fuels that perpetuate surface fires (Agee, 1993). Without frequent fires, open woodlands and savannas in many regions are replaced by closed-canopy forests through the normal processes of stand development (Oliver, 1980, Agee, 1993, Nowacki and Abrams, 2008, Staver et al., 2011).

More than a century of fire exclusion throughout the western U.S. has interrupted historic patterns of both natural and anthropogenic fire activity on the landscape (Agee, 1996, Sugihara et al., 2006). Dendrochronological studies indicate that frequent fire (between-fire intervals of < 20 years) was common in many low- and mid-elevation Pacific Northwest landscapes, most of which have not burned in the last century (Taylor, 2000, Skinner et al., 2006, Bekker and Taylor, 2010, Van de Water and Safford, 2011). This shift in fire regimes has resulted in the ingrowth of fire-sensitive species, resulting in denser vegetation and increased fuel loads in many western forests (van Wagtendonk, 1984, Agee, 1993, Sugihara et al., 2006). Along with the consequential increase in landscape homogeneity, these changes in the structure and composition of forests increase the risk of high-severity wildfires.

Rich in both ecological and cultural values, montane California black oak (*Quercus kelloggii* Newb.) woodlands of the Pacific Northwest have experienced a dramatic decline since the advent of large-scale fire exclusion (Scholl and Taylor, 2010, Cocking et al., 2014, Crotteau et al.,

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2014, Long et al., 2016b). Mature black oaks provide nesting cavities and platforms for a variety of birds and wildlife, and their mast supplies a critical food source for numerous species (Long et al., 2016b). Black oak woodlands were regularly burned by tribes in order to maintain and facilitate access to important dietary, medicinal, and material resources provided by this "cultural keystone" species (Anderson, 2005, Long et al., 2016a). Much of the degradation of these woodlands can be attributed to the absence of fire, and the consequent invasion of white fir (*Abies concolor* (Gord. & Glend.)), a highly pyrophobic species, and coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*), which is sensitive to fire prior to maturity (Ryan and Reinhardt, 1988). Continued suppression from neighboring conifers weakens oaks and ultimately causes mortality (Cocking et al., 2012). Black oak has several adaptive strategies that confer competitive advantages over conifers in fire-prone landscapes, including protective bark that permits above-ground survival of low intensity surface fires, epicormic bole and crown sprouting that enable recovery from crown injury, and vigorous basal sprouting that outpaces conifer regeneration after high-intensity fire has topkilled above-ground vegetation (McDonald, 1980, Donato et al., 2009a, Cocking et al., 2012, Collins and Roller, 2013, Crotteau et al., 2014). These advantages are lost, however, in the absence of fire. The removal of fire from the landscape has resulted in the transition of many oak woodlands and savannas to dense, mixed-conifer forests (Barnhart et al., 1996, McDonald and Tappeiner, 2002, Skinner et al., 2006).

Where the decline of black oak woodlands has resulted in the loss of important regional resources, opportunities remain for oak restoration, particularly following moderate and high-severity wildfires. Previous studies (Cocking et al., 2014, Crotteau et al., 2014) found that a single high-severity wildfire can re-establish oak overstory dominance following decades of ingrowth of competing fire-sensitive conifer species. To evaluate the effects of repeated wildfires on black oak persistence, we examined sprout vigor and shifts in patterns of community structure and composition across a continuous spectrum of fire severity combinations following two mixed-severity wildfires that burned through the same area in 2000 (Storrie Fire) and again in 2012 (Chips Fire). We asked the following questions: (1) what were the effects of repeated fire on stand structure and composition across the range of fire severities? (2) were there interactive effects between the two fires on oak sprouting response? and (3) what were the effects of combined fire severity on regeneration of both oaks and conifers? Based on the results of previous studies (Cocking et al., 2014, Crotteau et al., 2014, Hammett et al., 2017), we hypothesized that successive wildfires would set oak woodlands on a trajectory of recovery, given their competitive advantages over co-occurring fire-sensitive conifers. These results have implications for the management and restoration of oak woodlands across northern California and, perhaps more broadly, across the western region of the United States

2. Methods

2.1. Study area

This study was conducted within the intersection of the Storrie (2000) and Chips (2012) Fire extents in the southern Cascade Range in the Lassen National Forest in northern California, USA. Soils of the site are typically young and of volcanic origin, but also include granitic soils in the southernmost portion of the study area, where the Cascades and Sierra Nevada intersect (Kliewer, 1994). Climatic patterns are Mediterranean, with warm dry summers, and cool, wet winters, during which 95% of the annual precipitation is received (Kliewer, 1994). Elevations range from 900 to 1800 m above sea level (asl), with steep slopes dominating the terrain. Forest cover type in the study area is classified as Sierra Nevada Mixed Conifer (McDonald, 1980). Common overstory species are ponderosa pine (*Pinus ponderosa* var. *ponderosa* C. Lawson), sugar pine (*Pinus lambertiana* Douglas), coast Douglas-fir, white fir, incense-cedar (*Calocedrus decurrens* (Torr.) Florin), and California black oak. Common shrub species are deerbrush (*Ceanothus integerrimus* Hook. & Arn.), greenleaf manzanita (*Arctostaphylos patula* Greene), snowbrush (*Ceanothus velutinus* Douglas ex Hook. var. *velutinus*), Sierra gooseberry (*Ribes roezlii* Regal var. *roezlii*), mountain whitethorn (*Ceanothus cordulatus* Kellogg), and trailing snowberry (*Symphoricarpos mollis* Nutt.).

The Storrie Fire burned approximately 23,000 ha in the Lassen and Plumas National Forests (hereafter "Lassen" and "Plumas") in August of 2000. The Chips Fire burned approximately 30,000 ha in the same area, beginning in the Feather River Canyon of the Plumas, and quickly spreading onto the Lassen in August of 2012. The Chips Fire burned into the perimeter of the Storrie Fire, creating an overlapping reburn area of approximately 9,900 ha. Both wildfires burned at a mix of severities, allowing sampling across a spectrum of combined burn severity strata. Data collection occurred in the summer of 2015, three years after the Chips Fire, and 15 years after the Storrie Fire.

2.2. Field sampling

Ninety-three plots were established inside and adjacent to the 9,900 ha reburn area, ranging in elevation from 900 to 1600 m asl. Our sampling design used Monitoring Trends in Burn Severity project (MTBS, www.mtbs.gov) classifications of burn severity in order to stratify the Storrie Fire area into categories of burn severity (unburned, low, moderate, and high), and then paired these with the same classes of Chips Fire severity, for a total of 16 possible burn severity combinations (i.e., unburned-unburned, unburned-low, unburned-moderate, etc.; Fig. 1). Within areas where California black oak was present, we selected plots randomly within the previously defined strata using ArcGIS (ESRI, Redlands, California, USA). Plots were located at least 10 m from roads and trails to avoid edge issues. We further excluded areas with evidence of subsequent post-fire management activity (e.g., post-fire salvage, fuel mastication).

To characterize stand overstory structure and composition before and after each fire, we established 0.045 ha fixed-area circular plots. Within each plot, we recorded species, diameter at breast height (DBH; 1.37 m above ground), and percent live crown for all live trees > 2.5 cm DBH. Basal diameter, snag condition class (Thomas et al., 1979), and fire history (e.g., killed in Chips Fire, topkilled the Storrie Fire, or survived both fires) were recorded for all dead stems > 1.37 m tall. Designations of Storrie Fire, Chips Fire, and other causes of mortality were made based on snag condition class and other visual cues (e.g., presence of unconsumed bark on snags, substantial consumption of snags and stumps, considerable decay of old snags). Substantially burned snags and stumps were identified to species where possible using remnant bark or wood samples, and classified to genus where field identification was unreliable due to deterioration of samples (Cocking et al., 2014, Hammett et al., 2017). Locations for all measured stems within each plot were mapped and recorded using distance and azimuth from plot center.

Oak sprout vigor was assessed using a nested "focal oak" subplot (as in Cocking et al., 2014). Within each larger plot, we located the nearest living California black oak (mature tree or sprout clump) to plot center that was ≥ 1.37 m tall, and used that individual as the locus for a single10 m radius (314 m^2 area) circular plot. All living and dead sprouts emerging from the base of this "focal oak" were counted and the fire that triggered their formation (sprouted post-Storrie Fire or sprouted post-Chips Fire) and diameter at 20 cm above ground level were recorded. Substantial size differences between 15-year old sprouts (Storrie Fire origin) and three-year old sprouts (Chips Fire origin), as well as minimal consumption of live (at the time of the Chips Fire) vegetation in the second fire made identifying each sprout generation unambiguous (Hammett et al., 2017). Live and dead oak sprout clump crown diameter and live emergent height were measured for this clump, as well as for two additional randomly selected clumps per plot.